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Diurnal and Seasonal Patterns of Temperature and Wind Flow in the Planetary Boundary Layer for Ten Locations in Complex Terrain

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by

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16. ABSTRACT

In support of the Complex Terrain Model Development program, climatological summaries in the form of vertical profiles of wind and temperature were produced from a special computer file of radiosonde data created from twice daily observations recorded at ten National Weather Service stations located in the Rocky Mountain and Great Basin regions of the United States. Seasonal and diurnal patterns were presented showing terrain influence at each radiosonde location characteristic of early morning and late afternoon conditions. Although climatological patterns were related to the particular valley-ridge topography of the radiosonde site, terrain influence can be estimated at nearby site where data are required for studies of the planetary boundary layer, as in atmospheric dispersion modeling.

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DIURNAL AND SEASONAL PATTERNS OF TEMPERATURE AND WIND FLOW IN THE PLANETARY BOUNDARY LAYER FOR TEN LOCATIONS IN COMPLEX TERRAIN

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1. INTRODUCTION

Although mountain valleys differ in size, shape, orientation and other topographic features, their meteorology is similar. The effect of topography is to decouple the planetary boundary layer from the synoptic patterns and gradient winds by development of local circulations, temperature inversions and up-valley and down-valley flows. Since dispersion and fate of airborne pollutants must be determined by conditions within the decoupled boundary layer, it would be useful to observe the magnitude and depth of terrain influence that might be expected at locations where enough data are available to specify the influence.

The National Weather Service (NWS) operates a network of ten radiosonde stations in the Rocky Mountain and Great Basin regions of the United States that record vertical profiles of wind, temperature and relative humidity, twice daily, at 1200 GMT (0500 MST and 0400 PST) and 0000 GMT (1700 MST and 1600 PST). Soundings at these times afford an opportunity to observe conditions of maximum diurnal contrast between early morning temperature inversion conditions and down-valley flow and late afternoon instability and up-valley flow.

* On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Climatological summaries prepared from these data should reveal patterns of temperature structure and winds in the vertical profile of each radiosonde location that characterize the nature and depth of local terrain influence in the planetary boundary layer.

The purpose of the paper is to develop graphical climatological summaries, based on available radiosonde observations, that will illustrate pertinent features of terrain influence at ten locations of complex terrain. Summaries are compiled for winter and summer seasons by grouping data for three months (December, January and February), (June, July and August), and then by time of observation (0000 and 1200 GMT).

A comprehensive climatological study by Holzworth and Fisher (1979) summarized pertinent features of NWS radiosonde data in the lower few km of the atmosphere over the entire United States, 76 locations. Summaries were by season, observation times, and based on inversion frequencies and other features of vertical temperature structure. Results were presented as plotted percentages and isopleths on a map of the United States, and, although the ten radiosonde stations of this paper were included, their method of presentation did not emphasize description of terrain influence.

An investigation of temperature inversions in deep mountain valleys by Whiteman (1982) in western Colorado described the influence of terrain by use of tethered-balloon and special radiosonde observations, and the data were presented on graphical summaries of vertical cross sections versus hour of operation. There were twenty-one days of observations among five locations, and, while valuable information was obtained about inversion structure

and breakup, much more sounding data are required to characterize the influence of topography from a climatological aspect.

2. DATA

Radiosonde data used in this study are on magnetic computer tapes from the National Climatic Data Center, Asheville, North Carolina for the years 1971 to 1976. Although the soundings are scheduled for 0000 and 1200 GMT, balloon releases occur about 45 minutes early, and times of observation for the surface and lower levels of the sounding correspond to 0415 and 1615 MST for all radiosonde stations except those in Nevada where the times are 0315 and 1515 PST.

Summaries are prepared for Denver (DEN) and Grand Junction (GJT), Colorado; Salt Lake City (SLC), Utah; Ely (ELY), Winnemucca (WMC) and Yucca Flat (UCC), Nevada; Winslow (INW), Arizona; Albuquerque (ABQ), New Mexico; Boise (BOI), Idaho; and Lander (LND), Wyoming.

Data are summarized at the surface and at successive 50 millibar levels up to 500 millibars. Wind data are summarized as a resultant wind vector of all observed wind vectors, and the resultant vector is plotted in graphical form as a wind-arrow whose direction is the resultant direction and whose barbs indicate resultant speed in knots. A full barb represents a speed of 10 knots, a half barb 5 knots, and a shaft with no barb indicates a resultant speed less than 2.5 knots. Temperature data are summarized as averages in degrees Celsius and plotted alongside the resultant wind-arrow.

3. DISCUSSION

Fig. 1 shows summarized temperature and wind profiles for all ten radiosonde stations during the winter season at 1200 GMT (0415 MST). Stations are identified by three-letter abbreviations across the top of the diagram, with the altitude below in km and tenths. The two left-side columns identify levels of data in radiosonde ascents from the surface to 500 mbs and the average heights of each level in km and tenths. If station altitude is greater than the 850 mb average height (DEN, ELY, ABQ, and LND), then summaries are omitted for that level.

Patterns of temperature and winds apparent in Fig. 1 represent an incorporation of synoptic conditions experienced at these locations during the period 1971 to 1976 at 0415 MST in winter, and it is reasonable to assume they characterize the meteorology of the particular location where they were observed and reveal any terrain influence. Average temperatures in each profile reveal inversion conditions with increasing temperatures from the surface to some level aloft, usually the next level reported; however, at GJT, ELY, and INW warmest temperatures were found at the second level in the profile. A maximum of inversion temperature difference of 6.4 C is observed at UCC, with INW second with 5.2 C.

Wind patterns show the influence of terrain induced drainage flow of down-valley winds. Indeed, the orientation of valley topography at each site can be recognized by inspection of the wind direction arrows at the surface and first or second levels. For example, at GJT, resultant wind directions from

the southeast at the surface and 850 mb level correspond to the southeast to northwest slope of the Colorado River Valley at that point. At SLC, observations are taken at the base of the Jordan River Valley, which lies due south, and whose cold-air drainage probably explains the southerly resultant vectors at the surface, 850 mb and 800 mb levels. BOI is located within the Snake River Valley where the southeasterly resultant wind direction at the surface parallels the southeast to northwest valley gradient. Similarly, valley locations and terrain gradients can explain the resultant surface and low level directions at ELY, WMC, UCC, INW, and LND. An exception is Denver (DEN) where the location is not truly in a valley, however, the surface wind arrow displays a light southwesterly flow, perhaps indicating drainage from the Front Range of the Rockies through the South Platte River Valley. Vertical extent of drainage flow can be observed from the pattern of resultant wind vectors from the surface to about 750 mbs; above that level the gradient flow predominates.

Fig. 2 presents summarizations of vertical profiles of temperature and wind in winter at 0000 GMT (1615 MST). Comparison with Fig. 1 reveals diurnal changes in the planetary boundary layer, some profiles modified by terrain influence. Although temperature lapse rates between 50 mb levels are within the neutral to unstable range that would be expected, resultant winds at some locations indicate an upvalley regime prevalent as a climatological feature, as indicated by a 180 degree reversal from the 1200 GMT resultants at the surface and lowest levels. This phenomenon is suspected at GJT, SLC and BOI, while at DEN, ELY, WMC, UCC, INW, and ABQ the drainage flow evident in the morning appears to have been replaced by a synoptic pressure gradient-influenced pattern. There is no apparent difference at LND.

Summer morning profiles are illustrated in Fig. 3, and when compared to winter conditions indicate down-valley flow with greater depth at some locations. However, surface inversions seem to be shallower with only INW having a profile where the warmest temperature appears at the second level above the the surface. A maximum inversion temperature different again is evident at UCC, 7.1 C, with a second highest different at WMC, 4.9 C.

Patterns of resultant wind vectors at GJT, SLC, ELY, and ABQ indicate down-valley flows extend to a level 50 mbs higher than in Fig. 1. A greater resultant speed at DEN also suggests an increased drainage flow from the Southwest at that location. A lesser depth is suggested at UCC, WMC and BOI, and LND shows a summer pattern similar to winter.

Fig. 4 summarizes temperature and winds when the planetary boundary layer is most unstable, summer observations at 1200 GMT (1615 MST, 1515 PST). If a superadiabatic lapse rate is one that exceeds a decrease of 1.20 C/100 m, then the average temperatures in Fig. 4 indicate superadiabatic conditions from the surface to the first layer above at all locations except DEN and GJT. In a five-year (1961-1964) climatological study of summer (June, July and August) radiosonde data from WMC, Holzworth (1979) found superadiabatic lapse rates 71% of the 1515 PST observations in the layer from the surface to 100 m, and the temperature patterns in this figure would tend to confirm the prevalence of this instability at WMC and infer similar conditions at SLC, ELY, UCC, INW, ABQ, BOI, and LND.

At DEN, a 180-degree reversal in resultant direction from the morning pattern is observed at the surface, and light northeasterly resultants are also

present at 800 and 850 mbs suggesting a frequent up-slope flow towards the Front Range of the Rockies. Up-valley flow is also suggested at GJT, SLC, ABQ, and BOI.

4. CONCLUSIONS

Radiosonde observations are often the only data available that provide insight into the structure of the planetary boundary layer in regions of complex terrain. In such cases, the potential usefulness of radiosonde measurements should not be overlooked when estimates of terrain influence are required studies of atmospheric dispersion.

This paper has illustrated that available radiosonde data from locations in complex terrain can be utilized to produce climatological summaries capable of detecting terrain influence in vertical profiles of temperature and resultant wind vectors. Seasonal and diurnal patterns are presented that further describe modification of the planetary boundary layer by underlying topography.

Although climatological patterns are related to the particular valley-ridge topography of the radiosonde location, they can prove helpful in estimating terrain influence at nearby valley sites where information is required for studies of the planetary boundary layer, as atmospheric dispersion.

5. REFERENCES

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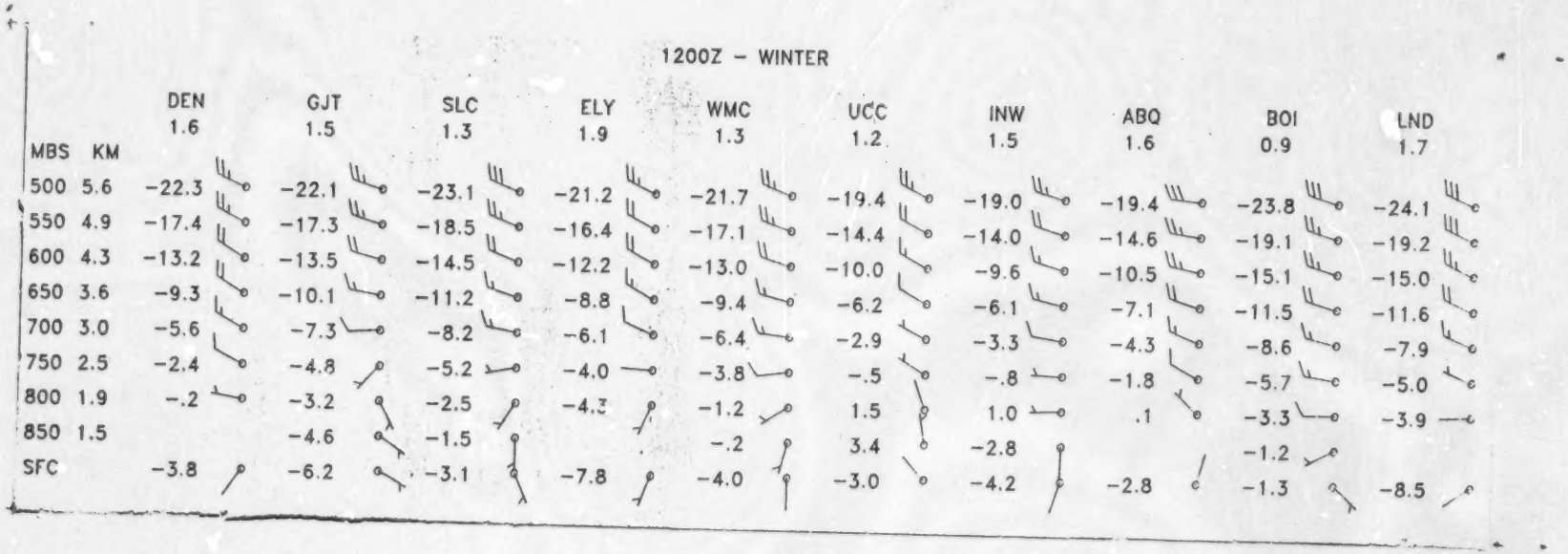

Figure 1. Average temperature (C) and resultant wind (kt), December - February, 1971 - 1976, 1200 GMT (0415 MST) radiosonde soundings.

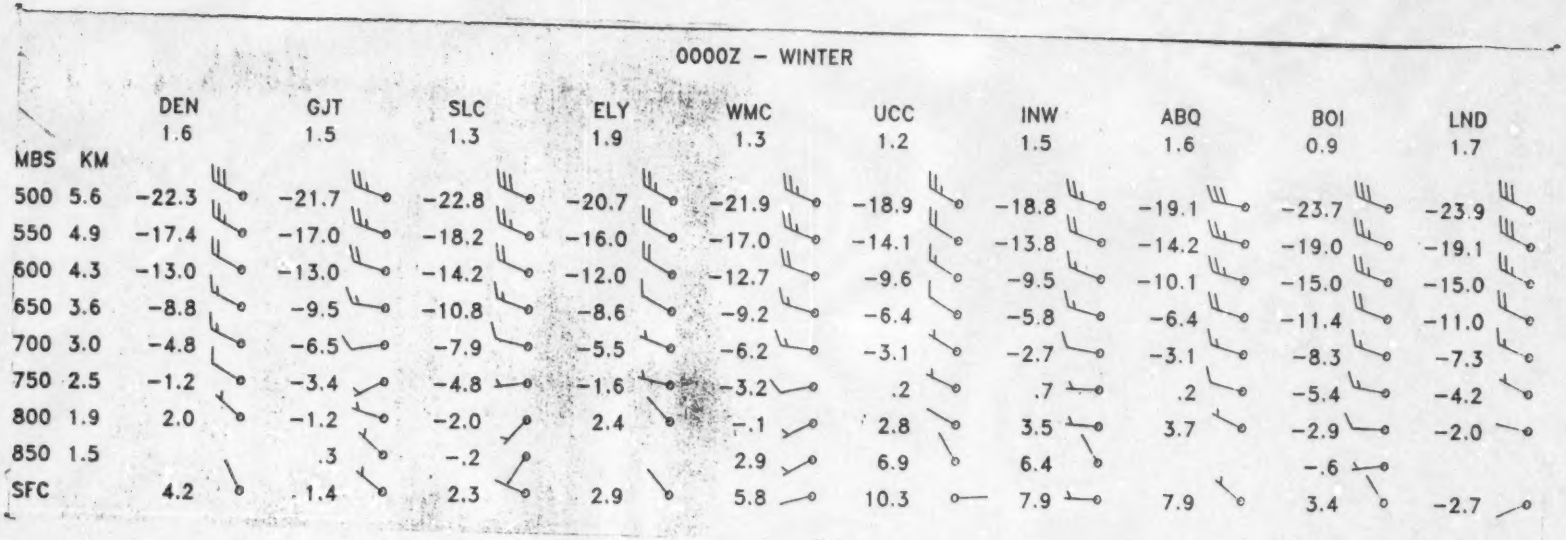

Figure 2. Average temperature (C) and resultant wind (kt), December - February, 1971 - 1976, 0000 GMT (1615 MST) radiosonde soundings.

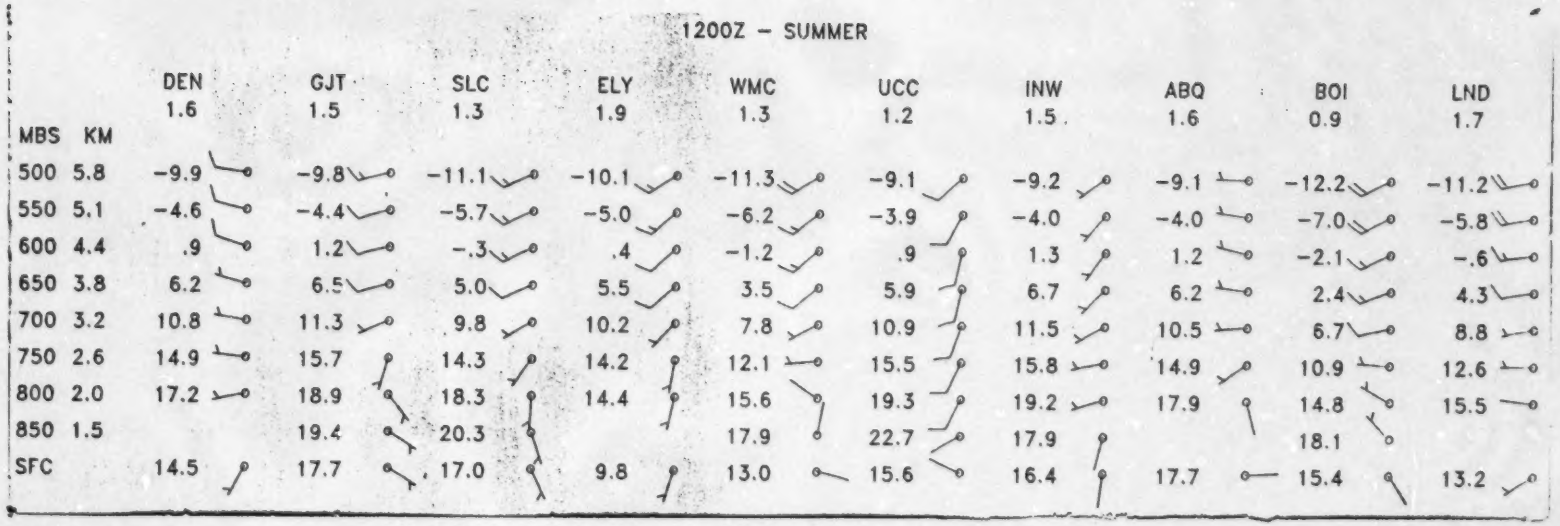

Figure 3. Average temperature (C) and resultant wind (kt), June - August, 1971 - 1976, 1200 GMT (0415 MST) radiosonde soundings.

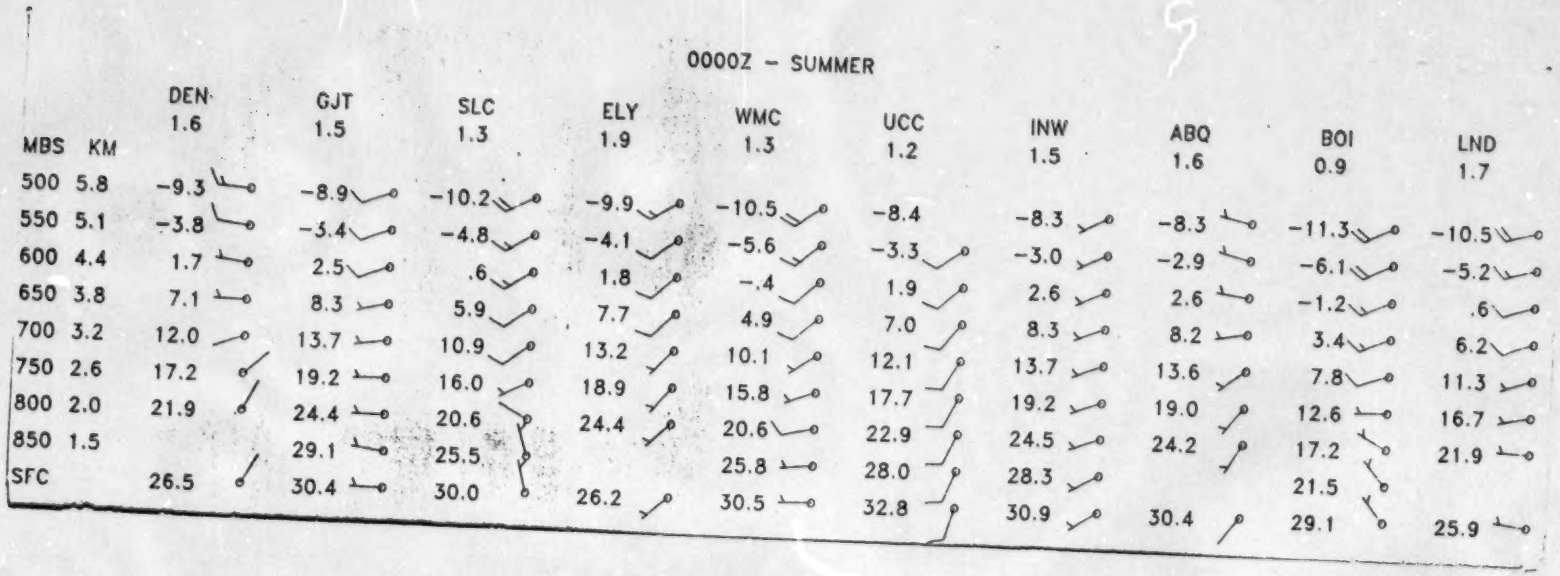

Figure 4. Average temperature (C) and resultant wind (kt), June - August, 1971 - 1976, 0000GMT (1615 MST) radiosonde soundings.